THE ALOUETTE II SATELLITE

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The Alouette II satellite was built by the Defence Research Telecommunications Establishment, Canada, and launched on 29 November, 1965 by the National Aeronautics and Space Administration of the U.S.A. as part of an international satellite programme for the study of the high atmosphere. The orbital parameters are:

apogee	2982 kilometers
perigee	502 kilometers
inclination	79.8° prograde
period	121.4 minutes
spin	2.25 revolutions per minute.

For the first orbit perigee occurred at 27° south latitude and the latitude of perigee moved south 1.89° per day. The satellite currently operates on command for about 6 hours per day, collecting data from one or more of the following five experiments:

1. A topside sounder, which measures the distribution of electrons in the topside ionosphere as a function of distance from the satellite,

2. A background radio noise experiment, which measures the noise environment from about 0.2 to 14 Mc/s,

3. A very-low frequency (VLF) experiment, which measures radio frequency emissions from 50 to 30,000 cycles per second,

4. An energetic particle experiment, which measures the flux of electrons with energies above 40 Kev, 250 Kev and 3.9 Mev, the flux of protons with energies above 500 Kev, above 100 Mev and in the range 1 to 8 Mev, and which measures proton spectra in the range 100 to 600 Mev.

5. An electrostatic probe experiment, which measures electron number density and temperature at two locations near the satellite surface.

A sister satellite, Explorer XXXI, was launched by the same vehicle and is in nearly the same orbit as Alouette II. On 29 January, 1966 the two satellites were 540 kilometers apart and were separating at a rate of 8 to 9 kilometers per day. Explorer XXXI contains ion and electron probes, and an electrostatic probe identical to the electrostatic probes on Alouette II.

The purpose of the dual launch is to permit nearly simultaneous comparisons between the data obtained by the sounder, VLF and electrostatic probe experiments in Alouette II and the probes in Explorer XXXI, and to provide ion and electron temperature and ion composition data at the height of the satellite for use with the sounder data. Since the distribution of electrons between the peak of the F layer of the ionosphere (the height of the peak of the F layer ranges from about 200 to 500 kilometers) and the satellite can be determined from the sounder records, use of this data in conjunction with the data measured at the satellite by the probes is expected to provide a great deal of information about the entire region above the peak of the F layer. In addition, comparisons can be made with data obtained from the Alouette I satellite (Warren 1962; Warren 1963; Belrose and Barrington 1963, DRTE report, 1966) launched on September 29, 1962, into a 1000 kilometer circular polar orbit, which is still providing 1 to 2 hours of topside sounder, VLF, background radio noise and energetic particle data per day.

The Topside Sounding Experiment:

The topside sounder in Alouette II provides an average pulse power of about 300 watts into the aerials at a pulse repetition rate of 30 per second and pulse width of

100 μsec. The sounder sweeps from 0.2 to 14.0 Mc/s, once every 30 seconds. It is normally on for periods of 13 minutes. The aerials used for the sounder are two dipoles, of length 240 feet and 75 feet tip to tip.

A topside sounder ionogram, taken when the satellite was at a height of 900 kilometers, is shown in Fig. 1. This record was obtained when the satellite was at a height of approximately 900 kilometers, near Bermuda. The axes of the ionograms are apparent range (time delay) in kilometers and frequency in Mc/s. The pulse repetition rate of 30 pulses per second provides 4800 kilometers of apparent range betwen sounder transmitter pulses. When the telemetry tapes are processed into ionograms, a height interval of 2000 kilometers with 100 kilometer apparent range markers, or of 4500 kilometers with 200 kilometer markers is usually used. To provide rapid identification, the markers at multiples of 1000 kilometers are made double the width of the other markers. The frequency sweep rate changes sharply at 2.0 Mc/s. This rate is about 0.15 Mc/s/sec below 2.0 Mc/s and 1.0 Mc/s/sec above 2.0 Mc/s. The slow sweep rate below 2.0 Mc/s enables the frequency of phenomena on the ionograms to be measured with an accuracy of ±5 Kc/s, or three times the accuracy that can be obtained with Alouette I.

The three characteristic reflection traces, the
X-wave O-wave and Z-wave are identified on the record. The
plasma resonance spikes (Lockwood 1963 Calvert and Goe 1963)
that occur at the plasma frequency, f_N, at the upper hybrid
frequency, f_T ($f_T^2 = f_N^2 + f_H^2$), and at the fundamental and
harmonics of the gyrofrequency, f_H and nf_H, are also identified.

An ionogram taken when the satellite was near
apogee is shown in Fig. 2. At apogee the reflection traces
usually show great retardation and there is often more than
one path of propagation by which the Z-wave may return to
the satellite. Electron densities of 10^3 to 10^4 electrons
per cubic centimeter are common near apogee, but very low
electron densities (less than 200 electrons per cubic
centimeter) are occasionally encountered at high latitudes.

An ionogram taken when the satellite was near
perigee is shown in Fig. 3. For these conditions, the
electron density at the satellite is relatively large, and
the reflection traces are strong. On this record, both earth
echoes and echoes from the top of a sporadic E layer are
present. The spikes occurring at harmonics of the electron
gyrofrequency (Lockwood 1965) are also identified.

The Very Low Frequency Experiment:

The very low frequency experiment is occasionally
operated simultaneously with the topside sounder and shares
the same broad-band telemetry channel. This mode of operation
produces mutual interference between the two experiments,
but for certain studies the potential advantages of the

combined experiment outweigh the disadvantages of the inter-
ference (Barrington et al. 1965). So far little of the
simultaneous data have been analysed. On several passes
per week, at various latitudes, the VLF experiment is
operated alone. On one such pass recorded over Australia
the event shown in Fig. 4 was observed. Here a normal
fractional hop whistler, i.e., the dispersed electromagnetic
impulse that has propagated upwards from a lightning discharge
to the satellite, is shown. A proton whistler (Gurnett, et al.
1965) and the first helium whistler (Barrington, Belrose and
Mather, 1966) that has ever been detected are also identified.
The dispersion of the fractional hop whistler can be used to
determine the total electron content along the whistler path.
The frequency at which the proton trace separates from the
fractional hop whistler (the cross-over frequency) determines
the relative abundance of protons at the satellite height,
while the dispersion in the tail of the trace can be used
to derive number density of protons at this height. The
dispersion of the helium whistler can be used to find the
number density of helium at the satellite, and the helium
cross-over frequency in a function only of the relative
abundances of the various ion constituents. Thus assuming
that the ionosphere at the satellite height is composed
solely of electrons, protons, helium ions and oxygen ions
a signal such as that shown in Fig. 4 contains information
from which the electron density at the satellite height as
well as the relative and absolute abundances of the ion
constituents (Barrington, Belrose and Mather, 1966) can be
deduced. In addition, sufficient information is available

to provide a check on the accuracy of the theory and measurements used in deriving the data.

The extended high frequency coverage of the Alouette II VLF receiver has permitted the detection of signals from several ground based VLF transmitters. In Fig. 5 the signals from one such transmitter may be seen at frequencies of 17.6 and 18.2 Kc/s. Considerable information on the propagation of VLF waves within the ionosphere can be obtained from studying the regions in which such signals are observed. Also shown in this figure is noise with a sharp lower cut-off frequency that has been triggered by a whistler. It has been suggested (Brice and Smith 1964) that the lower cut-off frequency of such noise is the lower hybrid resonance of the plasma at the satellite height, and the facts to date seem to support this hypothesis (Barrington, Belrose and Nelms, 1965). For the orbit of Alouette II the lower hybrid resonance frequency lies between a few hundred cycles and 20 Kc/s, and the resonance frequency will be within the pass band of the Alouette II VLF receiver, whenever noise such as that shown in the figure occurs. Since this resonance frequency is related to the local electron density and the ion composition, this phenomena provides yet another source of information on the constitution of the ionosphere.

The Background Radio Noise Experiment:

The AGC voltage from the swept-frequency sounder receiver is monitored all the time that the topside sounder

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is operating. These data provide a measure of the background
radio noise level at the satellite as a function of frequency
within the sweep range of about 0.2 to 14 Mc/s. Essentially
this experiment is very similar to one carried in the
Alouette I satellite (Hartz, 1964a, 1964b, and 1964c), save
that in the present equipment the sweep range has been extended
with the result that data can be obtained at significantly
lower frequencies.

In general a portion of the record near the
upper end of the sweep range contains interfering trans-
missions that propagate up from the ground above the
frequency for which the ionosphere is a shield. Similarly,
there is evidence that a portion of the low end of the
frequency range, below the electron gyrofrequency also is
contaminated by ground transmissions. Between these two
limits, however, it is possible to identify at least the
following main types of noise and to get detailed quantitative
data on them:

(1) galactic noise, which exceeds the receiver noise
level at frequencies greater than about 0.8 Mc/s,

(2) noise emissions that appear to be generated within
ionosphere: these occur in the frequency range
between the electron gyrofrequency, f_H, and the
upper hybrid frequency, f_T, and

(3) solar noise emissions, which appear sporadically
above the galactic noise level and which extend
down in frequency to a lower limit of about
0.6 Mc/s: to date a number of Type III bursts
have been identified in the records but other

types of solar noise have not yet been found
at these same low frequencies.

The Energetic Particle Experiment:

The purpose of the energetic particle experiment
can be stated in general terms as follows: (1) to provide
data which will aid in the understanding of the mechanisms
responsible for the production and control of outer Van Allen
radiation zone particles, and of auroral particles, (2)
to study the related problem of entry into the earth's
magnetic field of solar and cosmic ray particles, and (3)
to study the general distortions which occur in the earth's
magnetic field as a result of its interaction with the solar
wind.

The experiment, which is an improved version of
one flown in Alouette I, consists of seven different counters
capable of detecting electrons with energies above 40 Kev,
250 Kev and 3.9 Mev and protons above 500 Kev, in the range
1 to 8 Mev and above 100 Mev and of measuring proton spectra
in the range 100 to 600 Mev. Most of the detectors are
directional, that is they measure intensities in a small
range of angles about a given direction which is determined
with respect to the direction of the earth's magnetic field
by magnetometers on board the satellite. At the time of
writing all detectors are operating normally.

The experiment is capable of a time resolution
of about 1/8 of a second although in most of the analysis
counting rates averaged in 1 second and 4 second intervals
will be used. Automatic data processing equipment forms
an important part of the experiment since more than 10^6 data

points per month are obtained and it is necessary to plot
all of these in the initial part of the analysis. The
data from the telemetry tapes are first transferred to
digital magnetic tape and the processing is done on an IBM
360 computer. The computer output is then plotted off-line
on a EAI 3500 Data plotter.

One type of measurement which could not be made
with Alouette I but which can be made with the present
experiment is electron pitch angle distributions. One
directional detector looks out at right angles to the
satellite spin axis and, for most satellite orientations,
this detector sweeps out an appreciable range of angles
with respect to the magnetic field direction during a half
spin period (about 13.5 sec). Fig. 6 shows two examples of
electron pitch angle distributions obtained in the outer
radiation zone at an L value of about 6. A study of the
shape of such distributions, particularly in the loss cone,
may yield information about the mechanisms responsible for
precipitation of electrons into the atmosphere.

The Electrostatic Probe Experiment:

A pair of thin cylindrical electrostatic probes
(Brace, Spencer and Dalgarno, 1965; Spencer et al., 1965;
Brace and Reddy, 1965) are employed on the Alouette II
satellite for investigating the following:

    (1)   the nature of the plasma in the immediate
               vicinity of the spacecraft,

    (2)   the potential of the satellite relative to the
               plasma, and the nature of its variations,

    (3)   the nature of the ion and electron wake which
               forms behind the satellite as its leading surfaces

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sweep out the ambient particles in its path.

The two probes are used independently and sequentially. A repeating sawtooth voltage is applied to the probe which is in use, and the resulting current which flows to the probe from the plasma is detected and transmitted to recording stations on the earth (Fig. 7). The amplitude and curvature of these volt-ampere characteristics permit the electron concentration and temperature along the orbital path to be derived at about one second intervals. Four linear ranges of current detection sensitivity permit the electron concentration to be measured when in the range of 10^2 to 10^6/cc. The electron temperature can be resolved in the range of approximately 200 to 20,000°K. Fine structure in the electron concentration along the satellite path can be detected if its dimensions exceed approximately one hundred meters.

Measurements of the satellite potential are particularly important in a satellite having an extremely long antenna in which large voltages are induced by their high velocity through the geomagnetic field. The satellite's potential can be resolved when it lies between -10 volts and +2 volts. This is done by noting the voltage which must be applied to drive the probe to the plasma potential. The gross nature of the ion and electron wake can be derived by observing the roll modulation of ion and electron currents as the probes pass behind the satellite.

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Figure Captions:

Figure 1: An Alouette II topside sounder ionogram recorded
when the satellite was near Bermuda, at an altitude
of 900 kilometers. The various reflection traces
are identified.

The Z-wave plasma frequency at the satellite,
f_ZS, occurs at $X = 1 + Y$
The O-wave plasma frequency at the satellite,
f_N, occurs at $X = 1$
The X-wave plasma frequency at the satellite,
f_xS, occurs at $X = 1 - Y$
The plasma spikes observed at the satellite occur
at the following frequencies:
f_H, the electron gyrofrequency, occurs at $Y = 1$
f_N, the plasma frequency, occurs at $X = 1$
f_T, the upper hybrid frequency, occurs at $X = 1 - Y^2$
nf_H, the multiples of the electron gyrofrequency,
occur at $Y = \frac{1}{2}, \frac{1}{3}, --- \frac{1}{n} ---$.

Figure 2: An Alouette II topside sounder ionogram recorded
when the satellite was near Bermuda, at an altitude
of 2802 kilometers.

Figure 3: An Alouette II topside sounder ionogram recorded
when the satellite was near Santiago, Chile, at
an altitude of 535 kilometers.

Figure 4: A VLF spectrogram, showing a proton and helium
whistler. The lower part of the figure is the
actual spectrogram obtained from a sona-graph
spectrum analyser. The upper part of the figure
illustrates the idealized form of these whistlers.

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Figure 5: A "Rayspan" spectrogram, showing signals from VLF transmitters at 17.6 and 18.2 Kc/s. Also illustrated is a band of lower hybrid resonance noise at about 5 Kc/s. that has been triggered by the whistler echo of the fractional-hop whistler appearing at 3.5 seconds.

Figure 6: Pitch angle distributions obtained during two passes on day 336 (Dec. 2, 1965). In one spin period each pitch angle is sampled twice and the open and closed circles each refer to a half period.

Figure 7: A repeating sawtooth voltage (V_a) is applied to each cylindrical electrostatic probe and the current to each collector is measured by a multi-range current detector (I). Only one of the probes is shown here.